3 Suspension and Underwater Light Conditions

Suspension and underwater light condition measurements were made by WES, as well as by several other groups that studied Laguna Madre (Brown and Kraus 1997; Militello et al. 1997; Brown 1997; Cifuentes et al. 1997; and Burd and Dunton 2000). This chapter describes the total suspended material (TSM) measurements collected by WES and others which were used in the sediment model validation and the underwater light measurements made by WES.

Background

Reaches for Laguna Madre were defined by CESWG in their draft Supplemental Environmental Impact Statement for dredged material disposal to help organize information on the lagoon. Besides the obvious geographic break between Upper and Lower Laguna Madre, differences in vegetation type, benthic fauna, and nekton were used to sub-divide the system. Channel-reach divisions are defined in Table 8. These reaches were used to summarize TSM data.

WES TSM and underwater light measurements

Photosynthetically active radiation (PAR), optical backscatter (OBS), and TSM were profiled during the WES December 1996, June 1997, and November 1997 field surveys. Samples of TSM and light conditions were made by WES to supplement other underwater irradiance measurements, of which those Dr. Robert Maffione made for the Seagrass Productivity Model (SPM) team have been the most detailed and definitive to date. The PAR measurements presented here cover a different period of time.

Suspended samples were collected cooperatively by the Texas Water Development Board, U.S. Geological Survey, and Conrad Blutcher Institute in June 1997 at three tidal discharge ranges and analyzed by WES for TSM. Measurement ranges are shown in Figure 23. Select samples were also analyzed for calcium carbonate content (CaCO3), loss on ignition (LOI), and turbidity. Point water samples were collected by WES inside Laguna Madre during this period as our survey boat moved between bed-sampling locations. The samples were analyzed for TSM and turbidity.

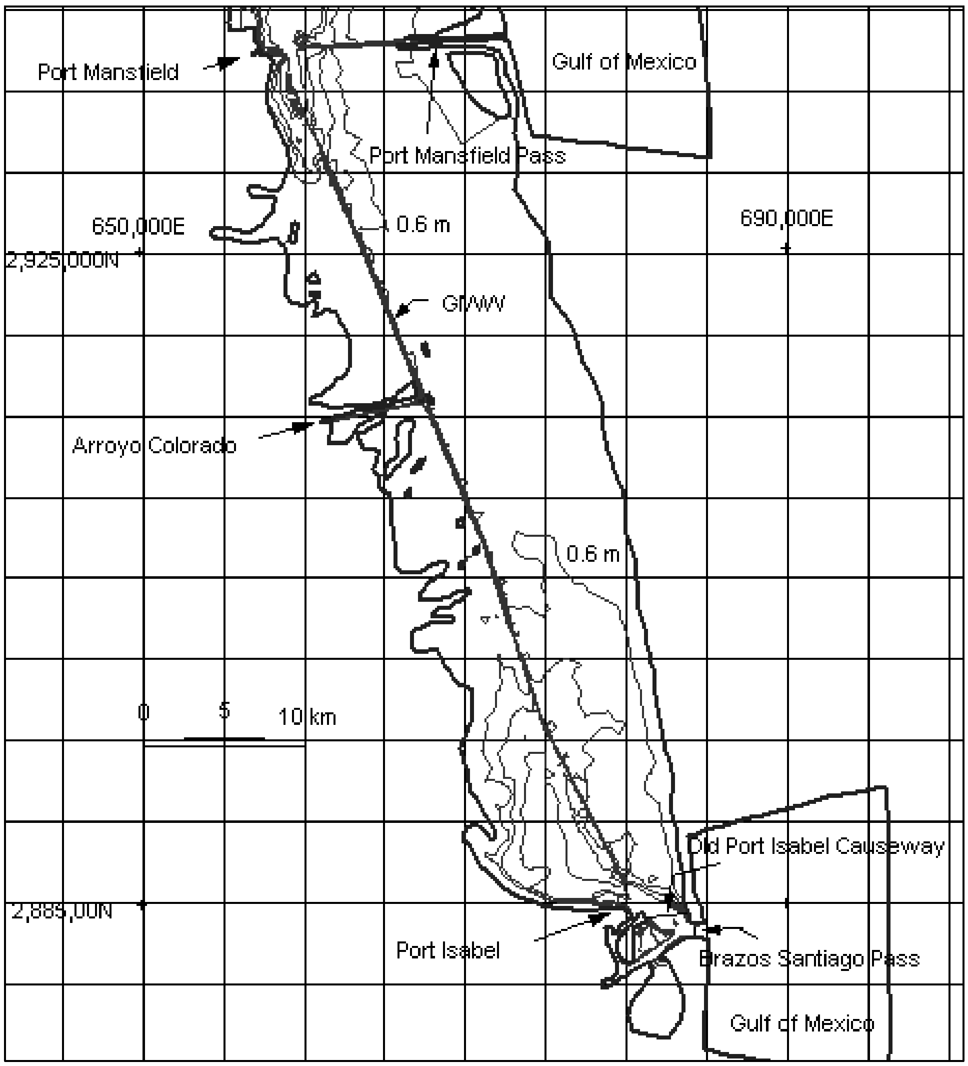

Figure 23. Measurement Ranges for the November 1997 Tidal Pass Survey

Table 8
Laguna Madre Reach Descriptions

Reach	Description	Latitude (N) at Northern End	Waterway Miles	Length, km
1	J.F. Kennedy Causeway to northern side of Baffin Bay	27° 36.2	553-572	30.6
2	Northern edge of Baffin Bay to north entrance to Land Cut	27° 22.8'	572-588	25.7
3	Land Cut	27° 9.4'	588-612	38.6
4	Southern entrance to Land Cut to south of Port Mansfield	26° 48.6'	612-638	40.2
5	South of Port Mansfield to south of Arroyo Colorado	26° 27.0'	638-649	17.7
6	South of Arroyo Colorado to Queen Isabella Causeway	26° 18.0'	649-665	25.7

Suspended sediment and floc characteristics were measured during November 1997. *In situ* floc size was determined photographically. Supporting determinations of light transmission, calcium carbonate, and TSM were made. Light transmission determined on filtrate and dispersed samples was used to determine the contributions of dissolved organic matter and particle aggregation. A complete description of these measurements was made by Knowles (1998).

Additional TSM samples were collected in close proximity to a pipeline discharge of dredged material during February 2000. Those results are presented in Chapter 5.

Texas Natural Resources Conservation Commission monitoring

The Texas Natural Resources Conservation Commission (TNRCC) has montiored TSM at seven stations along the GIWW in Laguna Madre since the early- to mid-1970s. Samples are collected quarterly by boat. Station locations are given in Table 9 and are arranged from north to south.

Conrad Blucher Institute TSM monitoring

A study group from the Texas A&M University, Corpus Christi, Conrad Blucher Institute (CBI) performed suspended sediment monitoring at a total of seven stations from 1994 to 1996 (Brown and Kraus 1997; Militello et al. 1997;

and Brown 1997) . Monitoring lasted as long as one year at each station. Samples were collected from platforms by ISCO ® 3700 automatic water samplers programmed to sample at 6:00 a.m. and 6:00 p.m. (0600 and 1800 hours) daily. Samples were filtered and the dry-weight residual used to quantify total suspended material (TSM).

Table 9
Location of TNRCC Monitoring Stations in Laguna Madre

TNRCC Station Number	Location	Latitude N	Longitude W
13443	JFK Causeway	27°-36.00'	97°-14.40'
13445	Bird Island	27°-28.75'	97°-19.25'
13444	Baffin Bay	27°-16.58'	97°-24.62'
13449	North of Port Mansfield	26°-47.00'	97°-28.00
13448	Port Mansfield	26°-34.00'	97°-24.00'
13447	Arroyo Colorado	26°-22.00'	97°-19.00'
13446	Port Isabel	26°-05.00'	97°-12.00'

Seagrass Productivity Model Team measurements

Suspended sediment samples were collected by the Seagrass Productivity Model (SPM) group and WES in February and March 2000. These samples were collected in the proximity of two dredging and disposal operations and along the Laguna Madre GIWW length. Measurements were compared to long-term monitoring data collected by the Texas Natural Resources Conservation Commission (TNRCC) and CBI.

Samples were collected at stations along the GIWW in duplicate, and mean values were reported. Samples were also collected 300 m in both directions from the working dredges along the GIWW. Some samples were also collected at adjacent locations within and outside of seagrass vegetated areas.

Satellite images

Satellite images can be used to gauge, qualitatively and in some cases quantitatively, the distributions of near-surface TSM. James et al. (1977) presented seven images taken by a LANDSAT satellite of Lower Laguna Madre from 1972 to 1975 and used them to infer circulation and TSM distributions.

LANDSAT 5 images of Laguna Madre were obtained from the U.S. Geological Survey- (USGS-) operated Earth Resources Observation System (EROS) Data Center. LANDSAT 5 orbits at 705 km on a 16-day, 233-orbit cycle. Orbits are sun-synchronous with a 9:45 a.m. equator crossing. The thematic mapper (TM) uses 16 sensors for the visible to mid-infrared wavelength bands, plus four thermal infrared sensors. The instantaneous field of view for bands 1 to 5 is 30 by 30 m. Multi-scanner bands are described in Table 10.

Table 10
LANDSAT 5 Band Wavelength and Color

LANDSAT 5 TM Band	Wavelength, μm	Dominant Color
1	0.45 - 0.52	blue
2	0.52 - 0.60	green
3	0.60 - 0.69	red orange
4	0.76 - 0.90	near infrared (N-IR)
5	1.55 - 1.75	mid infrared (M-IR)

Image data were preprocessed by EROS to calibrate the digital signals and remove geometric distortion. Radiometric calibration included both absolute calibration of sensor optics and electronics, and relative calibration to remove residual errors.

WES Methods

Underwater light

Profiles of PAR, OBS, and TSM with depth were made in Lower Laguna Madre during the WES field surveys of December 1996, June 1997, and November 1997. PAR covers roughly the 400- to 700-nm wavelength band. LI-COR, ® Inc. model LI-190SA and LI-192SA sensors were used on deck and underwater and were logged with a LI-1000 unit. Sensors of this design were originally calibrated by National Research Council of Canada. The manufacturer, using a National Bureau of Standards lamp, calibrated these particular sensors accurate to ±5 percent. Sensor readings were compared on deck before each profile and found to give very similar readings in every case. The in-air calibration constant for the LI-192SA was used to make the comparisons.

On site, the sampling boat was anchored about 20 min before measurements were made. Positions were obtained with the use of a differential global positioning system (DGPS). The underwater PAR unit was lowered on a weighted frame, away from the shadow of the boat. An OBS sensor and pump intake were located on the same frame and at the same vertical position as the PAR sensor. Simultaneous readings of underwater and in-air PAR were made to avoid the effects of irradiance fluctuations on attenuation calculations. OBS readings and pumped sampled were taken very close to the same times as the PAR measurements.

Suspended material

A tidal survey was performed in November 1997 to measure tides, tidal currents, and water characteristics in Lower Laguna Madre. Measurement ranges were established at Brazos Santigo Pass Channel, the Old Port Isabel Causeway, and Port Mansfield Pass Channel. Tidal discharges were measured with an Acoustic Doppler Current Profiler (ADCP) mounted on a boat that moved across measurement ranges. Between discharge transect measurements, 225-ml suspended samples were collected with an ISCO ® pump sampler. Samples were collected at channel quarter points of the Brazos Santigo Pass Channel and Old Port Isabel Causeway and at the centerline at Port Mansfield Pass Channel. Sampling depths at Brazos Santigo Pass Channel were 0.6 and 6.7 m; at Old Port Isabel Causeway, 1.2 and 2.1 to 2.4 m, and at Port Mansfield Pass Channel; 1.0 to 1.2, 2.4 to 3.0, and 4.0 to 4.9 m.

About every fourth sample from the tidal discharge ranges was analyzed for calcium carbonate content (CaCO3), loss on ignition (LOI), and turbidity. All point samples collected inside Laguna Madre were so analyzed.

Data and sample analysis

PAR. The Lambert-Beer law describes downward diffuse attenuation. Based on this law, a mean diffuse attenuation coefficient K_{dm} was estimated by nonlinear least squares fit to:

$$Q_z = Q_o \exp(-K_{dm} z) \tag{31}$$

where Q_z and Q_o are the underwater and in-air irradiance quanta, and z is depth. The diffuse attenuation coefficient for PAR (K_d) was also calculated at each depth by

$$K_d(z) = -\frac{1}{z}\ln\left(\frac{Q_z}{Q_o}\right) \tag{32}$$

OBS. Optical backscatter measurements were taken simultaneously with light profiles. The OBS sensor detects 680-nm scatter at about 180 degrees from the beam direction. Output voltages are roughly proportional to total suspended sediment concentrations and subject to the same particle-size dependence as other optical scattering measurements. A mean backscatter intensity OBS m was calculated for each profile.

TSM. Total suspended material was determined by the gravimetric method. Samples were filtered onto preweighed 0.4 µm pore-size Nuclepore ® polycarbonate filters. Filters were dried for one hour at 80 °C and reweighed. The total non-filterable solids is taken as TSM.

About 10 percent of the TSM samples from the tidal survey were analyzed in duplicate to gauge the repeatability of the TSM analysis. Seventeen samples from the WES November 1997 survey were analyzed five times each as a quality control assessment.

Turbidity. Laboratory determinations of turbidity were made with a Cole Palmer ® turbidity meter model 8391-50. The instrument was frequently calibrated according to AMCO® AEPA-1 primary standards at the 0.5 and 10 NTU levels.

CaCO3 and LOI. Four forms of carbon are often present in TSM: carbonate minerals, highly condensed organic carbon such as coal, altered organic carbon such as humic substances, and little altered remains of plants and animals. The inorganic carbonate minerals (calcium carbonate CaCO3) were determined by weak acid wash, and the remainder of the carbon materials, largely organic, were determined after combustion (loss on ignition LOI).

After TSM determinations were made, polycarbonate filters were replaced on the filtering apparatus. The filters were covered with 0.5 cm of 0.1 N Hcl and allowed to stand 4 min. A vacuum was then applied to draw the acid through the filters. The filters were rinsed with an equal volume of distilled water. This procedure was repeated a second time. The total weight loss after drying, as a percent of the TSM dry weight, was taken as CaCO3 percent.

Loss on ignition was determined after the CaCO3 determinations by firing the filters at 550 °C for one hour. Polycarbonate filters leave no residue after this procedure. The total weight loss as a percent of the TSM dry weight was taken as LOI percent.

Floc size. Underwater photographs were made with a special camera developed for this purpose. The *In Situ* Aggregate Analysis Camera (ISAAC) was developed at the University of North Carolina - Chapel Hill, Institute of Marine Science, and was operated by Dr. Stephen Knowles of Sedimentology Professionals, Inc. of Morehead City, North Carolina. ISAAC consists of a 35 mm SLR camera with macro lens, side-mounted collimated strobes, a pump system to collect samples, and a 5-cm pathlength SeaTech ® transmissometer, all mounted on a frame. Photographs were developed and negatives digitized at 2,700 dpi resolution to produce an 8-bit gray-tone digital image. The digital images were analyzed with an image processing program to produce size-class counts of floc numbers and floc shape information.

Results

PAR profiles

December 1996. Five PAR profiles were taken on 9 December 1996 along the axis of the deep, bare area in Lower Laguna Madre. DGPS locations are given in Table 11.

Table 11 Station Locations December 1996			
Time, CST	Station	Latitude N	Longitude W
1153	FIX3/b1	26°-10.9703'	97°-15.0318'
1237	FIX2/b2	26°-10.8447'	97°-15.3663'
1307	FIX1/b3	26°-10.7578'	97°-15.6017'
1400	S.LLM/b4	26°-08.3660'	97°-15.6523'
1453	S.LLM/b5	26°-06.3967'	97°-15.6067'

The "b" station sequence refers to bed sediment sample sites and designations. Bed sediment characteristics are presented in Chapter 4. Depth average optical and TSM values for these stations are presented in Table 12. Detailed results of the measurements are presented in Table 13.

Table 12 Depth Average Light and TSM for December 1996			
Time, CST	K_{dm}, 1/m	OBS, v	TSM, mg/l
1153	1.66	0.122	20
1237	2.11	0.212	42
1307	2.43	0.246	45
1400	1.75	0.171	37
1453	1.63	0.119	22

Table 13 Light and TSM Profiles for December 1996					
Time, CST	Depth, m	Q_z	K_d, 1/m	OBS, v	TSM, mg/l
12/09/96					
1153	0.30	915	1.88	0.12	19
	0.61	601	1.62	0.13	22
	0.91	398	1.53	0.12	19
1237	0.30	830	2.22	0.21	44
	0.61	465	2.07	0.22	40
	0.91	257	2.03	0.21	43

1307	0.30	779	2.29	0.22	41
	0.61	355	2.46	0.23	45
	0.91	129	2.75	0.28	50
1400	0.30	826	1.97	0.18	39
	0.61	543	1.61	0.17	34
	0.91	307	1.70	0.17	39
	1.22	158	1.83	0.16	36
1453	0.30	643	2.18	0.12	22
	0.61	477	1.59	0.12	21
	0.91	295	1.55	0.12	21
	1.22	235	1.36	0.12	22

June 1997. Seven PAR profiles were taken over three days at locations given in Table 14.

Table 14
Station Locations June 1997

Date	Time, CST	Station	Latitude N	Longitude W
6/18/97	1545	OBS/b6	26°-10.9216'	97°-15.2739'
6/19/97	1509	Baffin/b7	27°-11.5129'	97°-25.7059'
6/19/97	1700	UL2.5	27°-16.5385'	97°-24.5896'
6/20/97	1017	LLM3/b8	26°-35.3991'	97°-22.9373'
6/20/97	1208	LLM3.5/b9	26°-36.0581'	97°-25.8178'
6/20/97	1335	LLM3.7/b10	26°-33.6663'	97°-25.0518'
6/21/97	0953	LLM2/b11	26°-08.0838'	97°-12.4498'

Station OBS was very close to CBI station FIX2. Depth-averaged results are presented in Table 15 and detailed results are given in the Table 16.

Table 15
Depth Average Light and TSM for June 1997

Station	K_{dm}, 1/m	OBS, v	TSM, mg/l
OBS	4.09	0.399	43

Baffin	4.41	0.313	29
UL2.5	5.09	0.348	46
LLM3	1.84	0.185	14
LLM3.5	2.54	0.217	18
LLM3.7	3.88	0.488	74
LLM2	0.89	0.116	4

Table 16
Light and TSM Profiles for June 1997

Time,CST	Depth, m	Q_z	K_d, 1/m	OBS, v	TSM, mg/l
6/18/97					
1545	0.30	523.0	4.10	0.37	41
	0.76	78.2	4.10	0.40	44
	1.22	26.3	3.44	0.42	43
6/19/97					
1509	0.46	254.0	4.45	0.32	31
	1.07	41.8	3.59	0.32	26
	1.68	14.7	2.92	0.29	30
1700	0.61	3.8	5.18	0.35	45
	0.91	1.2	4.70	0.34	NA
	1.22	1.2	3.48	0.34	44
	1.83	0.3	3.09	0.36	48
6/20/97					
1017	0.30	597.0	2.73	0.18	14
	0.61	628.0	1.38	0.18	13
	0.91	292.0	1.75	0.19	14
1208	0.46	677.0	2.74	0.22	18
	1.07	238.0	2.04	0.21	16
	1.68	83.0	1.97	0.22	20
1335	0.30	398.0	4.22	0.49	73

	0.76	160.0	2.83	0.49	71
	1.22	54.3	2.66	0.49	79
6/21/97					
0953	0.30	911.0	1.22	0.12	3
	0.61	803.0	0.85	0.12	4
	0.91	718.0	0.81	0.12	4

November 1997. Two PAR profiles were taken in the field on 11 November and five PAR profiles were taken on 12 November 1997. DGPS locations are given in Table 17.

Table 17
Station Location and Times for 11 and 12 November 1997

Time, CST	Station	Latitude N	Longitude W
11/11/97			
1300	FIX1	26°-10.7840'	97°-15.6071'
1500	FIX1	26°-10.7840'	97°-15.6071'
11/12/97			
1146	N of #2 gage	26°-07.7462'	97°-14.4188'
1322	N of #2 gage	26°-07.7462'	97°-14.4188'
1449	N of #2 gage	26°-07.7462'	97°-14.4188'
1545	N of #2 gage	26°-07.7462'	97°-14.4188'
1631	N of #2 gage	26°-07.7462'	97°-14.4188'

Five profiles were taken in the field on 13 November 1997, as described in Table 18.

Table 18
Station Locations, Depths and Times for 13 November 1997

Time, CST	Station	Depth, m	Latitude N	Longitude W
0954	Port Isabel	2.13	26°-05.6060'	97°-12.1685'
1047	Daymarker 115	1.16	26°-08.2451'	97°-13.6872'
1139	FIX3	1.68	26°-10.9661'	97°-15.0295'
1313	Daymarker 67	1.83	26°-13.8549'	97°-16.2530'

1426	Port Mansfield	1.68	26°-33.8253'	97°-24.2516'

Tables 19 and 20 that follow summarize the depth-averaged and profile measurement results for the November 1997 survey.

Table 19
Depth Average Light and TSM for November 1997

Time, CST	Station	K_{dm}, 1/m	OBS, v	TSM, mg/l
11/11/97				
1300	FIX1	9.388	1.225	184
1500	FIX1	7.603	1.123	155
11/12/97				
1146	N of #2 gage	2.418	0.334	31
1322	N of #2 gage	3.339	0.494	68
1449	N of #2 gage	3.136	0.364	45
1545	N of #2 gage	2.966	0.389	49
1631	N of #2 gage	2.331	0.297	35
11/13/97				
0954	Port Isabel	1.187	0.158	5
1047	Daymarker 115	1.967	0.182	9
1139	FIX3	1.222	0.186	14
1313	Daymarker 67	1.834	0.201	15
1426	Port Mansfield	0.904	0.175	10

Table 20
Light and TSM Profiles for November 1997

Time, CST	Depth, m	Q_z	K_d, 1/m	OBS, v	TSM, mg/l
11/11/97					
1300	0.30	7.05	9.40	1.12	162
	0.61	0.62	8.46	1.18	NA
	0.91	0.07	7.78	1.20	165
	1.22	0.00	8.38	1.40	224

1500	0.30	10.20	7.64	1.07	NA
	0.61	1.88	6.86	1.12	NA
	0.91	0.27	6.87	1.15	146
	1.22	0.04	6.60	1.15	164
11/12/97					
1146	0.30	179.00	2.76	0.32	24
	0.61	100.00	2.29	0.32	27
	0.91	62.60	2.16	0.34	NA
	1.22	35.70	2.15	0.35	41
1322	0.30	278.00	3.55	0.46	48
	0.61	155.00	3.05	0.48	57
	0.91	56.20	3.14	0.51	NA
	1.22	20.20	3.15	0.52	98
1449	0.61	59.40	2.76	0.36	31
	0.91	26.30	2.69	0.38	NA
	1.22	4.90	2.47	0.35	42
1545	0.30	57.80	3.28	0.36	31
	0.61	28.10	2.76	0.36	NA
	0.91	13.70	2.57	0.42	34
	1.22	6.10	2.56	0.42	82
1631	0.30	29.10	2.80	0.28	22
	0.61	17.40	2.18	0.29	NA
	0.91	10.30	1.97	0.29	24
	1.22	4.80	2.08	0.32	58
11/13/97					
0954	0.30	730	1.55	NA	4
	0.61	624	1.04	0.145	NA
	0.91	342	1.34	0.160	4
	1.22	346	1.01	0.168	6

1047	0.30	728	2.59	NA	10
	0.61	562	1.74	0.180	8
	0.82	97	1.72	0.183	8
1139	0.30	1048	1.45	0.166	12
	0.61	804	1.19	0.186	NA
	0.91	551	1.21	0.189	14
	1.22	410	1.15	0.201	16
1313	0.30	880	1.92	0.190	16
	0.61	531	1.79	0.197	14
	0.91	302	1.81	0.215	16
1426	0.30	782	1.85	0.165	8
	0.61	362	2.16	0.174	NA
	0.91	247	1.85	0.178	10
	1.22	201	1.57	0.181	12

TSM and turbidity

The tidal survey quantified the TSM entering and leaving through the major tidal passes of Lower Laguna Madre. A total of 480 samples were analyzed for TSM. Time-series plots of averaged TSM and tidal discharge for Brazos Santiago Pass, the Old Port Isabel Causeway, and Port Mansfield Pass are shown in Figures 24, 25, and 26 . Time-series plots of CaCO3 and LOI percents, along with tidal discharge, are shown in Figures 27 and 28 for Brazos Santiago Pass and Port Mansfield Pass.

Laboratory determinations of turbidity, CaCO3, and LOI on suspended samples are shown in Figures 29 and 30 for Brazos Santiago Pass and Port Mansfield Pass. Turbidity is plotted against TSM concentration for the tidal discharge ranges and for the WES samples collected inside Laguna Madre in Figures 31 and 32.

There were statistically significant relationships between parameters shown in Figure 29 at p-values < 0.001. The level of CaCO3 as a percent of the TSM dry-weight was inversely proportional to the floc size and TSM levels and directly proportional to the LOI. Stated differently, the level of TSM correlated directly to floc size and inversely with the percentage CaCO3 and LOI.

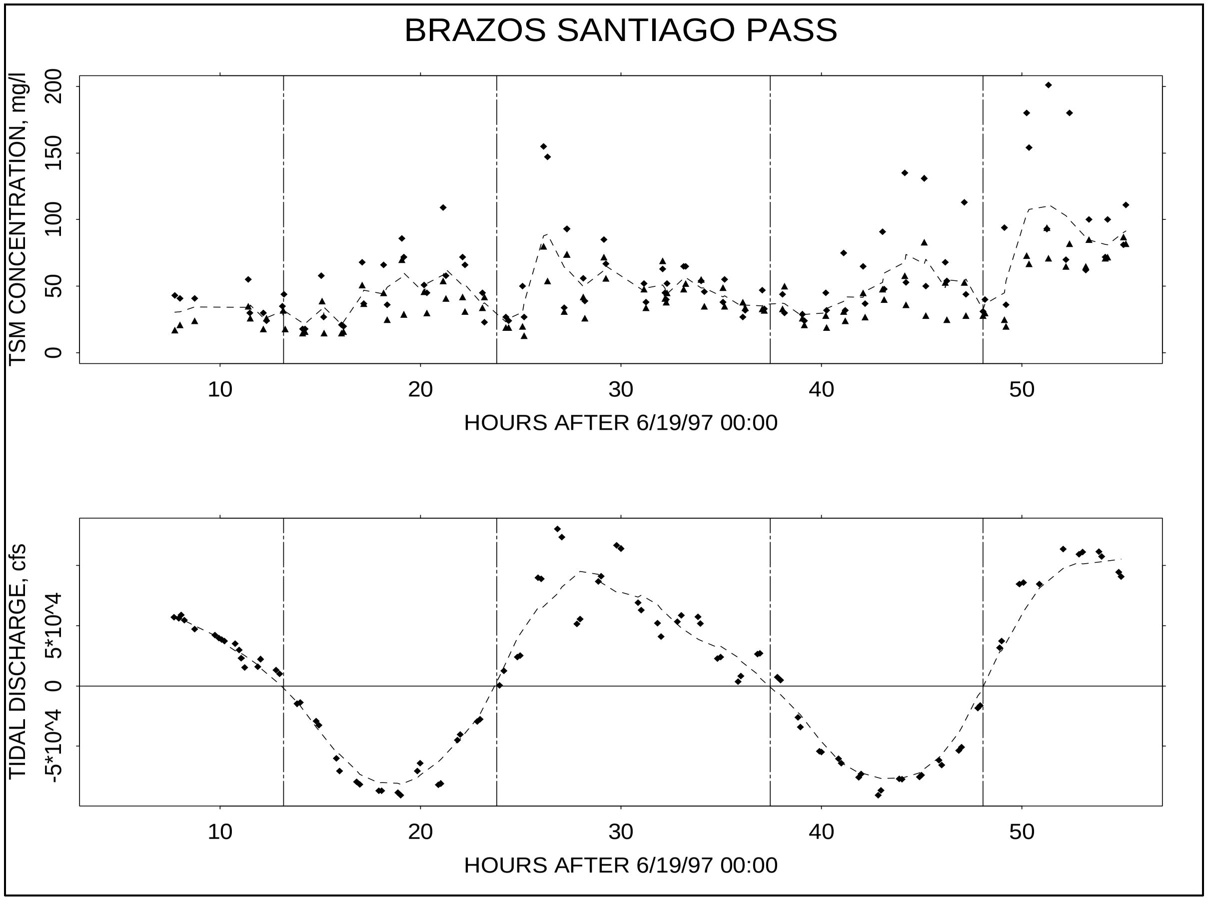

Figure 24. Tidal survey TSM and discharge time-series data for Brazos Santiago Pass (with trend lines), June 1997

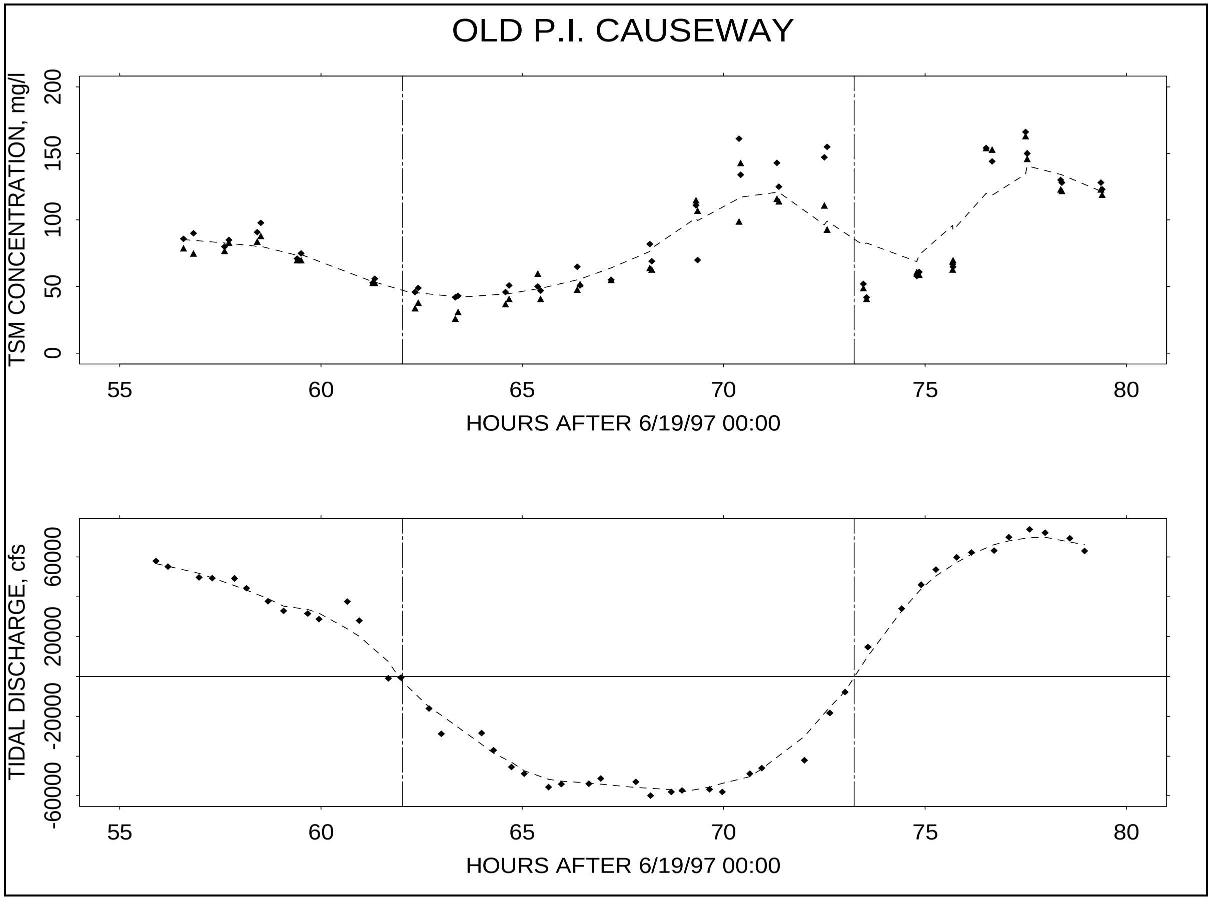

Figure 25. Tidal survey TSM and discharge time-series data for Old Port Isabel Causeway (with trend lines), June 1997

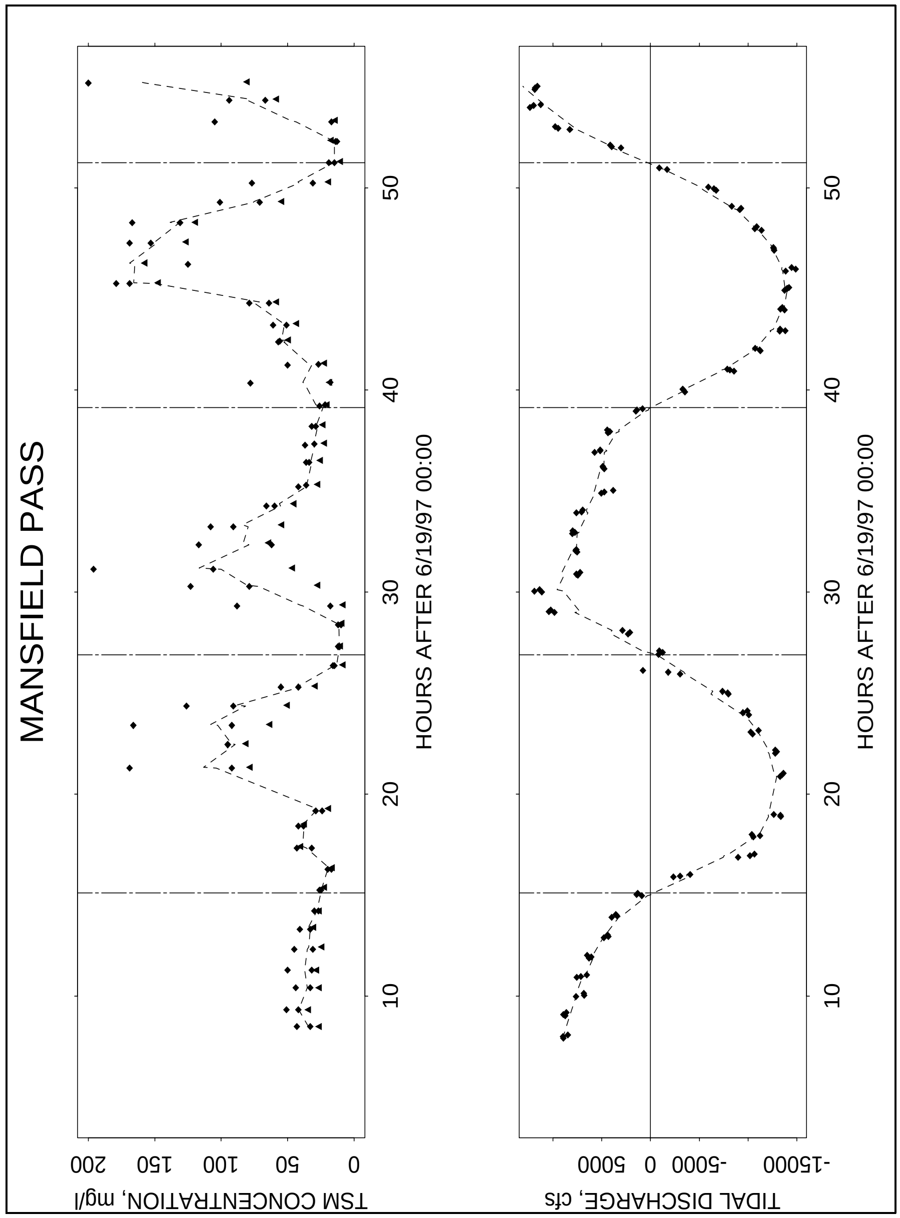

Figure 26. Tidal survey TSM and discharge time-series for Port Mansfield (with trend lines), June 1997

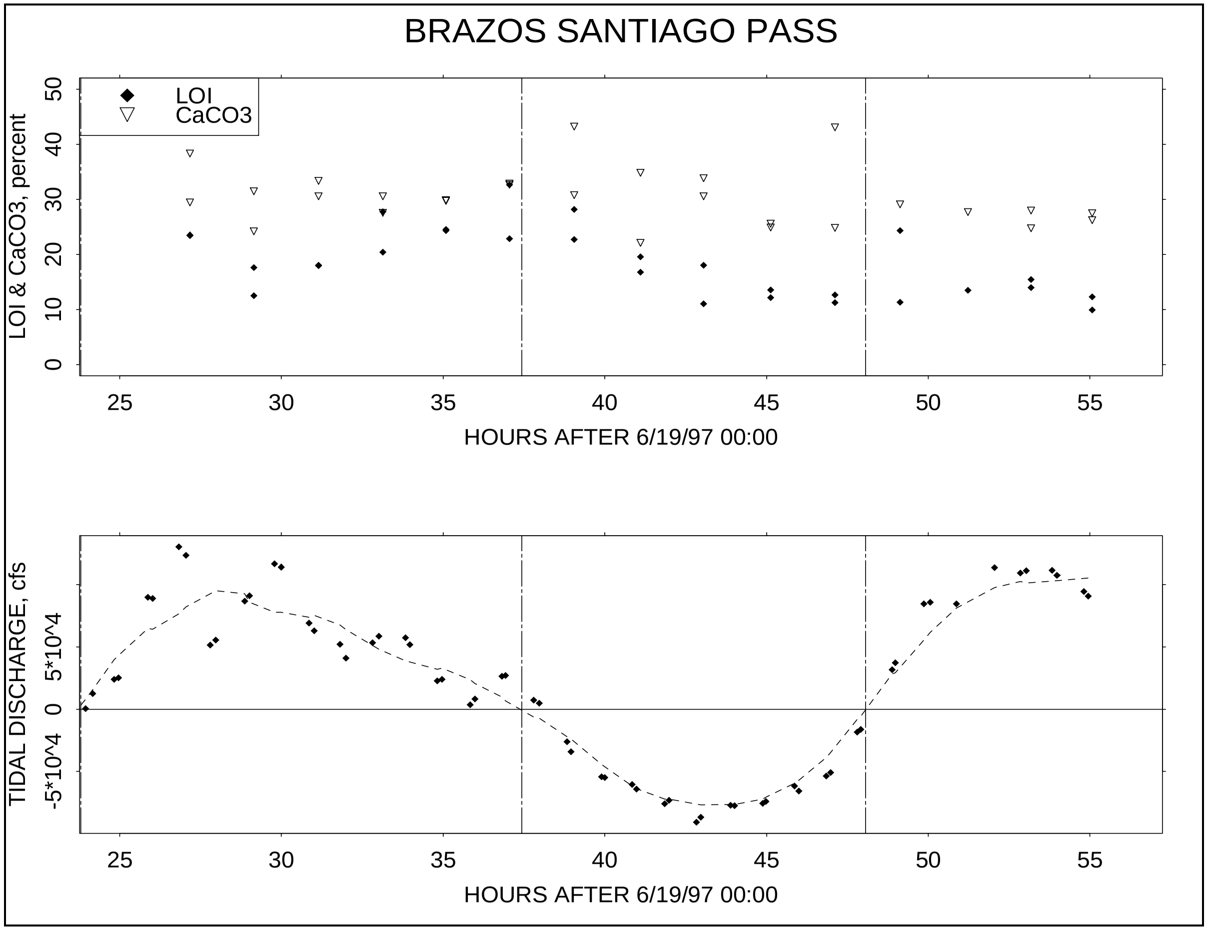

Figure 27. Tidal survey LOI and CaCO3 data for Brazos Santiago Pass, June 1997

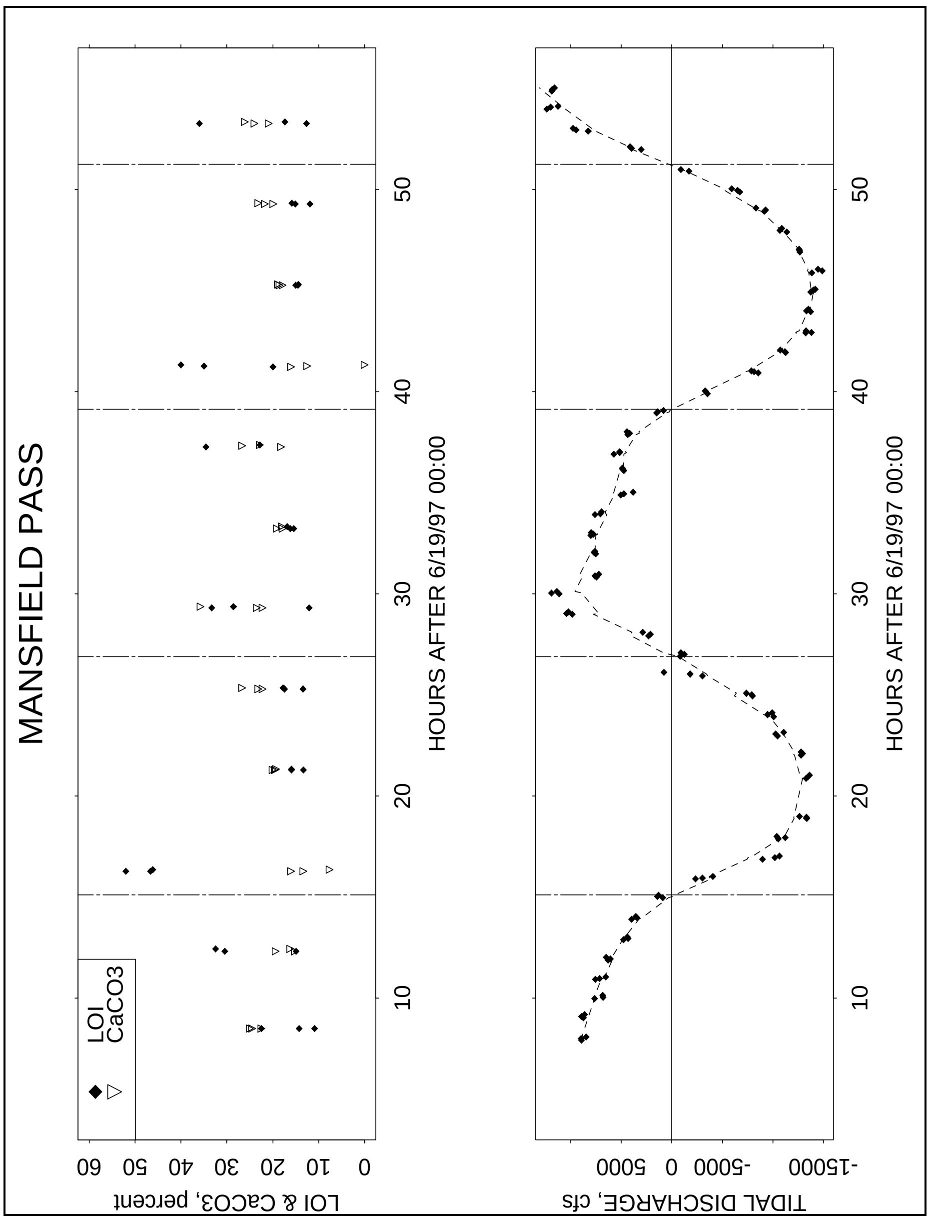

Figure 28. Tidal survey LOI and CaCO3 data for Port Mansfield Pass, June 1997

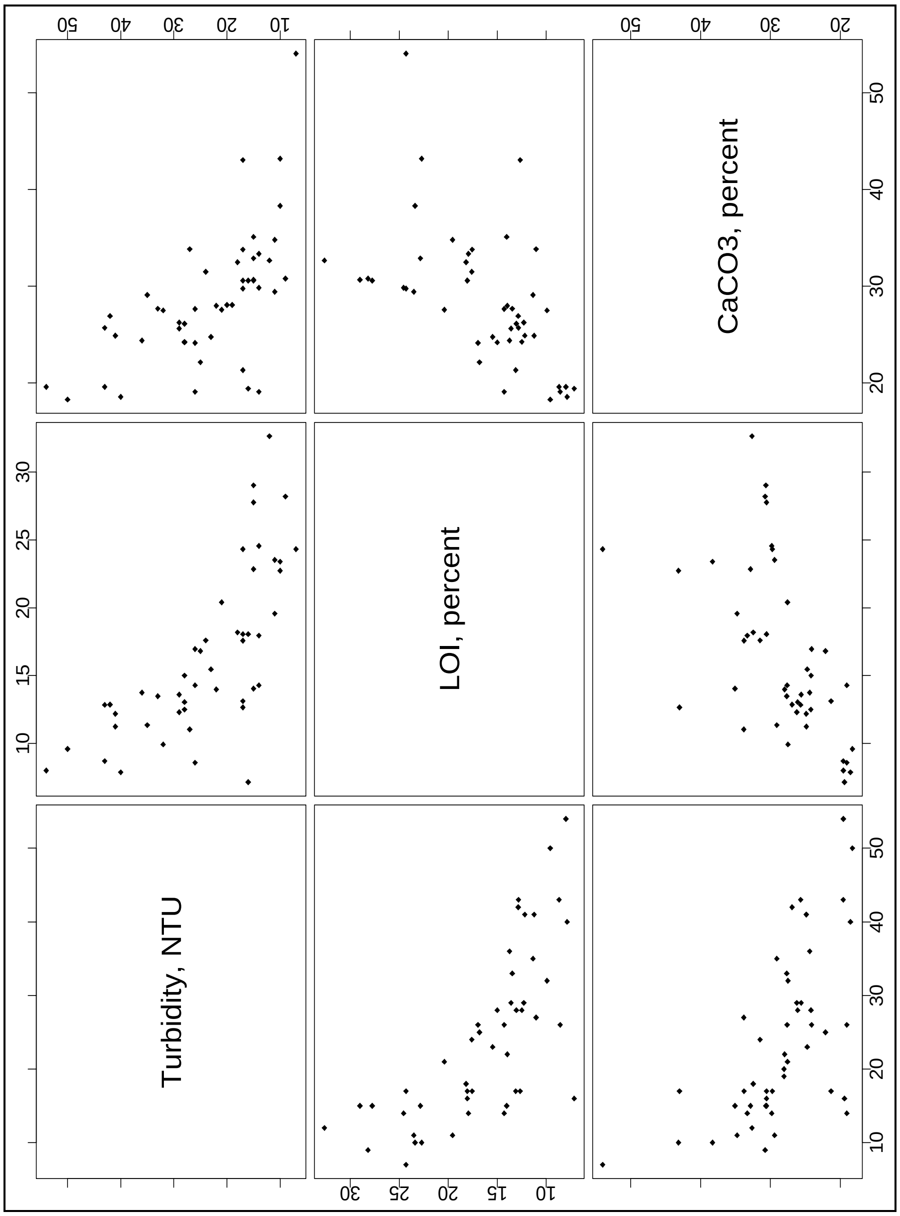

Figure 29. Scatter plots of turbidity, LOI, and CaCO3 against each other for the June 1997 Brazos Santiago Pass tidal survey

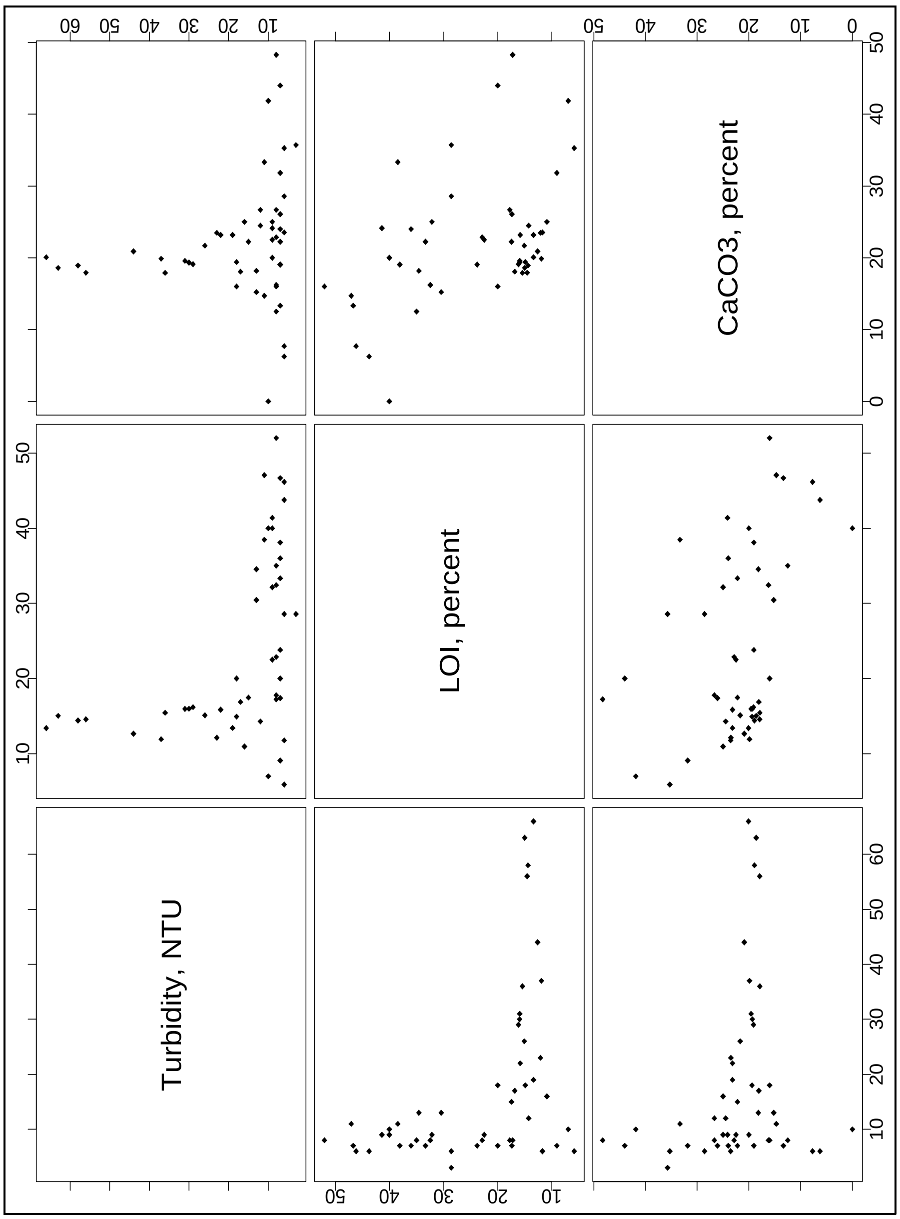

Figure 30. Scatter plots of turbidity, LOI, and CaCO3 against each other for the June 1997 Port Mansfield Pass tidal survey

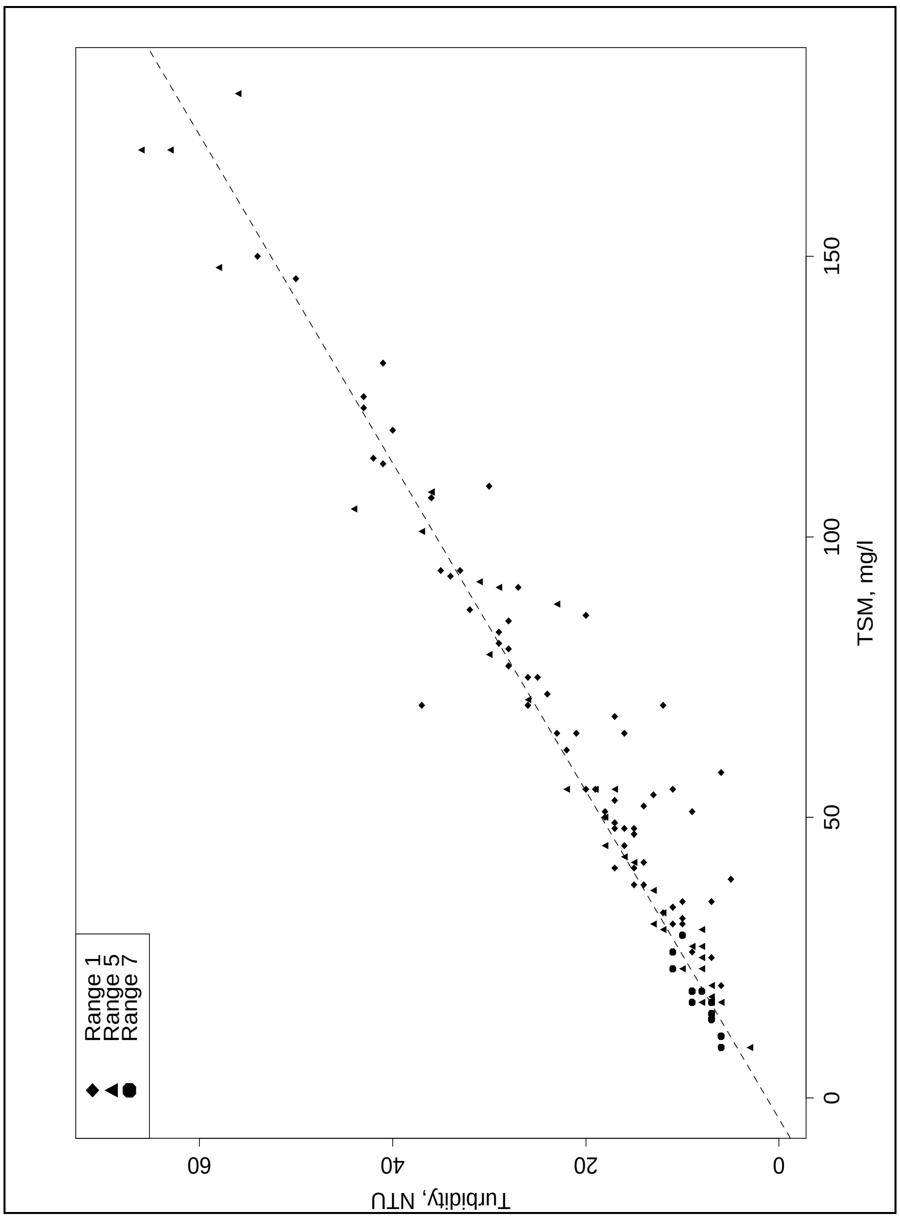

Figure 31. Tidal survey TSM versus turbidity for Brazos Santiago Pass, Old Port Isabel Causeway, and Port Mansfield Pass (Ranges 1, 5, and 7) with trend line, June 1997

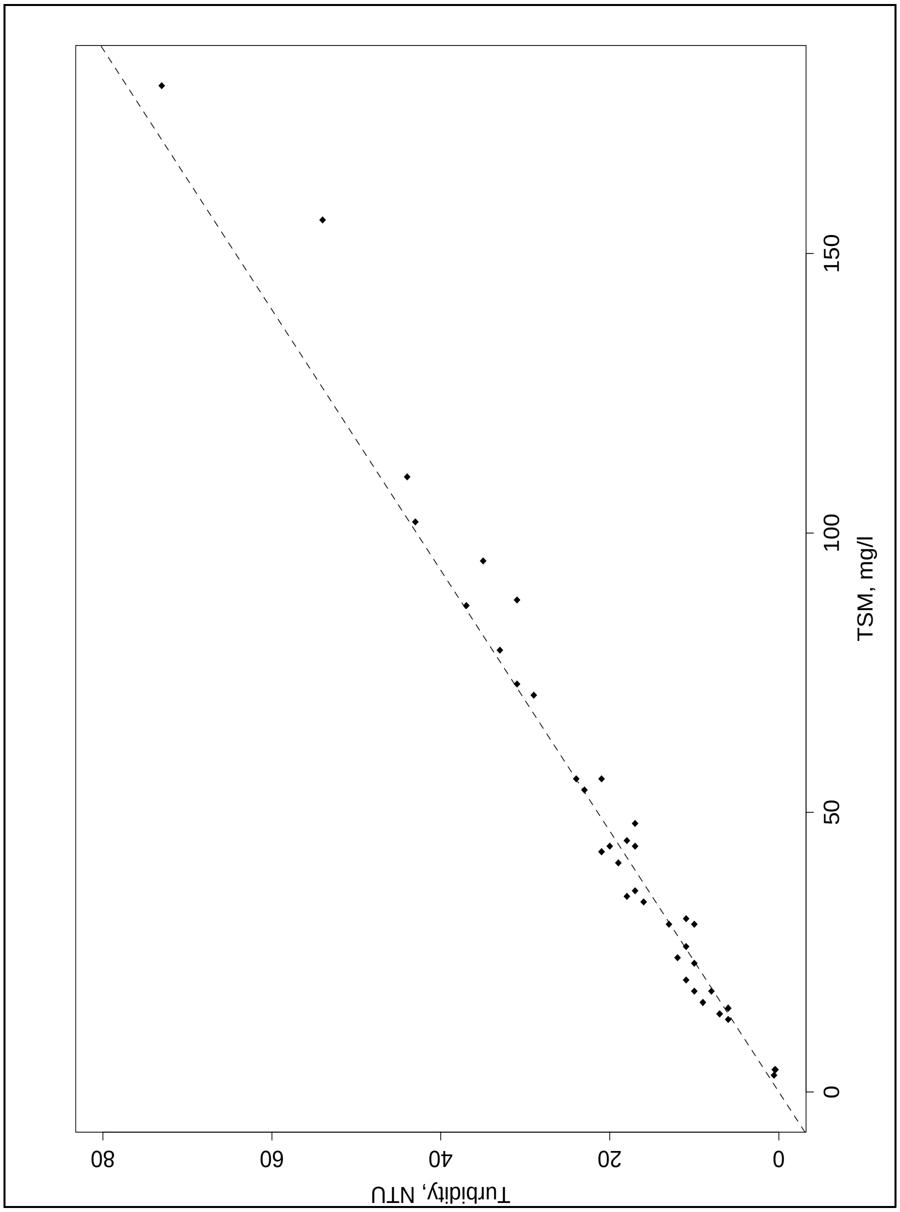

Figure 32. Relationship between TSM and turbidity for samples collected by WES within Laguna Madre (with trend line), June 1997

Sediment and floc characteristics

Field measurements and sampling were performed November 11 to 13, 1997 after a frontal passage occurred. Maximum wind speed on November 10 was 9.5 m/sec, and bed sediment resuspension was appreciable. Winds did not abate until early on November 11. Sampling proceeded as resuspended sediments settled and deposited, and water-column TSM concentrations decreased. Locations were the same as for the PAR profiling reported in a previous section. The measurement of floc size was limited by excessive TSM concentrations early in the survey, and, therefore, this parameter could not be measured at every sampling. Scatter plots of TSM, CaCO3, LOI, and mean floc diameter in µm are shown in Figure 33.

Fine-grained particulate matter usually defines the optical properties of suspensions, as discussed earlier in this chapter. Suspended material occurs as low-density, fragile flocs, which are best sized *in situ* to avoid sampling problems. Under contract with WES, Dr. Stephen Knowles, Sedimentology Professionals, Inc., used an underwater photographic instrument to collect *in situ* floc size and shape data. Sampling was synoptic with the PAR measurements reported in the earlier section.

Equipment used in the survey included a special underwater camera, a 5-cm path SeaTech® transmissometer, and a pumped water sampler deployed at seven locations from Port Isabel to Port Mansfield. The frontal passage that occurred prior to the sampling brought high winds from the North. The survey documented the settling phase which occurred after this meteorologic event. Values of TSM began with a maximum of 261 mg/l at the beginning of the survey and decreased to 4 mg/l early on the last day of the survey.

Floc size was obtained from image analysis of back-lit photographs. Floc sizes averaged 205 µm (standard deviation of 42 µm), TSM averaged 52.1 mg/l (standard deviation of 59 mg/l), and transmissivity averaged 53.1 percent (standard deviation of 23.3 percent).

Results from the floc-size measurements suggest that cyclical changes in floc size occur out of phase with cyclical resuspension/deposition events driven by frontal passage winds. During the initial phase of resuspension, floc size is small, even though suspended concentrations are high, due to high turbulent shear in the water column and near the bed. As the winds, waves, and turbulent-shear abate, but while suspended concentrations are still high, floc size reaches a maximum. As suspension concentrations decrease during deposition, floc size also decreases until it reaches a minimum when suspension concentrations reach minimum.

Example floc size, TSM and total suspended sediments (TSS: TSM - CaCO3 - LOI) results for 13 November 1997 at 0.76-m depth are presented in Table 21. Station locations and depths are given in Table 18.

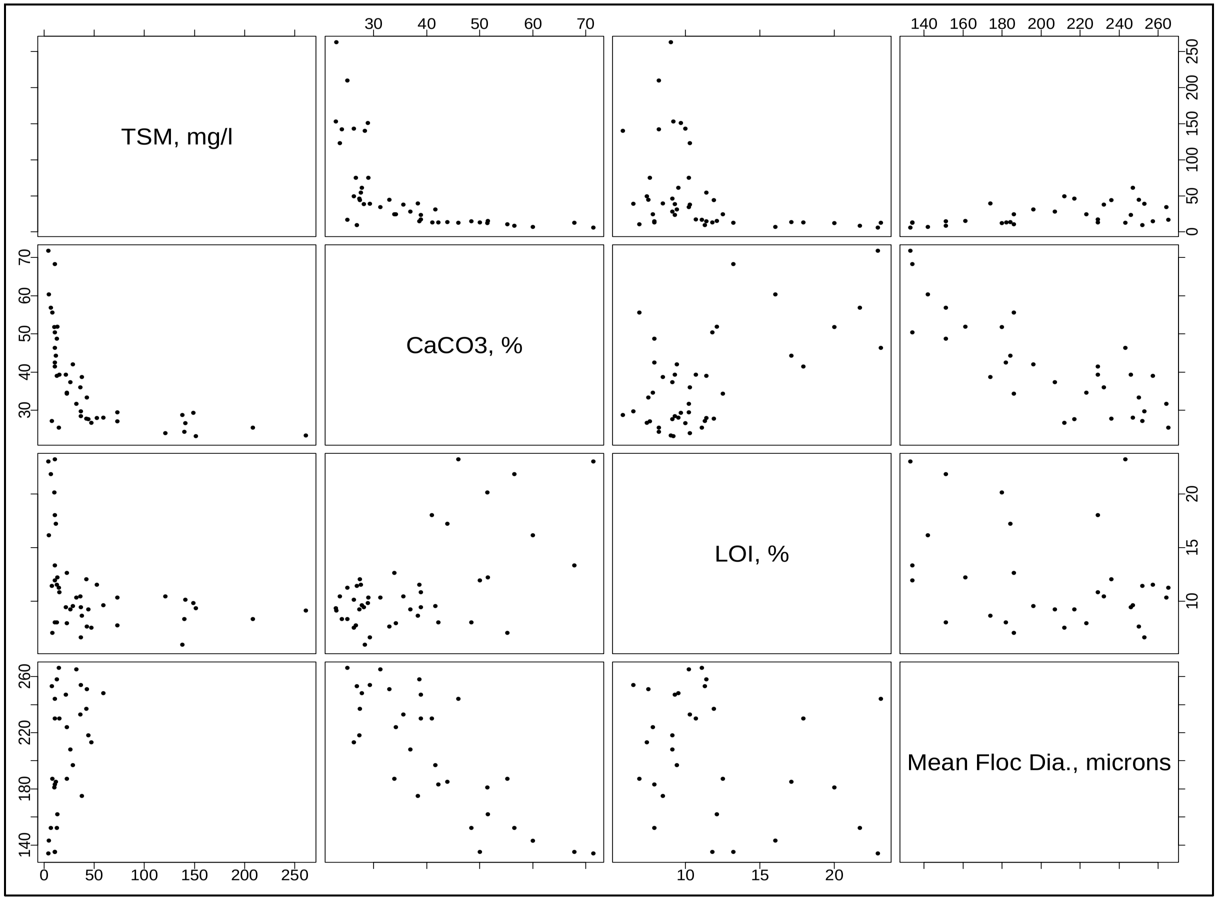

Figure 33. Scatter plots of TSM, CaCO3, LOI, and floc size (µm) against each other. Data from Lower Laguna Madre taken November 1997

Table 21 Floc Size and TSS at 0.76-m Depth on 13 November 1997 (See Table 18 for Locations)					
			Floc Size Distribution		
Station	TSM, mg/l	TSS, mg/l	Mean, μm	Std Dev., phi	Skew
Port Isabel	12 9	7 5	151 142	0.72 0.84	0.46 -0.26
Daymarker 115	19	11	134	0.74	0.51
FIX3	17	10	180	0.76	0.58
Daymarker 67	23	15	229	0.81	0.65
Port Mansfield	18	11	229	1.00	1.14

SPM measurements of TSM

During February and March 2000, the Laguna Madre Seagrass Productivity Model team made a series of six transects along the length of Upper and Lower Laguna Madre to collect water samples for TSM determination. Transects were made 8, 9, and 22 February and 15, 29, and 30 March. This data set was collected during a period when two dredges were working in the GIWW, one in Upper Laguna Madre and one in Lower Laguna Madre. The data set is important for that reason and also because it produced, perhaps, the most synoptic TSM data set covering the entire lagoon.

Samples were collected in bare areas along the GIWW at a series of stations established for this purpose. At some stations, samples were also collected in adjacent vegetated areas, although these spot measurements will not be reported here. In addition, samples were collected within about 300 m north and south of where the dredges were working at the time of the surveys. These samples were not necessarily collected in visible plumes, but in the general areas suspected of being negatively impacted by the dredging and disposal. Replicate samples were collected, and the mean of the replicates was used to quantify the TSM. Station locations identified by the lagoon reaches defined in Table 8 are given in Table 22.

Table 22 Seagrass Productivity Model GIWW Station Locations			
Station	Reach	Latitude, N	Longitude, W
5	1	27° 40.85'	97° 13.605'
6	1	27° 36.37'	97° 15.292'

7	1	27° 30.438'	97° 18.402'
8	1	27° 27.228'	97° 20.078'
9	1	27° 25.023'	97° 21.288'
10	2	27° 21.582'	97° 22.932'
11	2	27° 17.177'	97° 24.540'
12	2	27° 12.718'	97° 25.491'
ULM3	2	27° 11.55'	97° 25.7'
13	3	27° 7.593'	97° 26.479'
14	3	27° 2.485'	97° 26.789'
15	3	26° 57.357'	97° 27.207'
16	3	26° 52.323'	97° 27.833'
17	4	26° 47.477'	97° 28.107'
18	4	26° 42.457'	97° 26.981'
19	4	26° 37.983'	97° 25.353'
20	4	26° 33.784'	97° 24.366'
21	4	26° 28.965'	97° 22.286'
22	5	26° 23.325'	97° 20.249'
23	6	26° 16.341'	97° 17.148'
24	6	26° 12.149'	97° 15.660'
LLM1	6	26° 10.75'	97° 15.6'
25	6	26° 7.318'	97° 13.262'
26	6	26° 5.184'	97° 12'

Not all transects were completed as equipment reliability and weather conditions were not always favorable. Those familiar with the notorious wind conditions that arise in Laguna Madre might appreciate the SPM field crew member’s noting ".. lucky to be alive" as they made landfall at Port Manfield. Since transects always started at the north end of the system, Station 21 and greater had two to four missing values each, and thus the southern end of the system, Reach 6, was underrepresented in the sampling. Thus, sampling methods probably biased the TSM results for Reach 6 toward lower values.

Results by channel reach for select TSM percentiles, means, 95 percent confidence internals (95% CI) for the means, and numbers of samples are given in Table 23.

Table 23
Summary of Seagrass Productivity Model TSM Measurements (mg/l)

	Percentile						
Reach	25	50	75	Mean	95% CI		n
1	13.8	18.3	24.2	20.5	17.1	24.0	29
2	20.1	22.0	25.1	26.0	20.1	31.9	24
3	11.6	18.4	23.6	21.9	15.1	28.7	23
4	12.1	16.9	24.2	21.2	15.6	26.9	27
6	11.0	18.2	24.0	22.8	13.1	32.4	14
all	12.6	19.5	24.5	22.4	20.0	24.8	121
Near-dredge	23.1	37.8	62.9	49.7	33.5	65.9	22

Paired samples at SPM Stations 9, 11, "new," and 25 were collected near the GIWW in unvegetated areas and adjacent seagrass areas. However, the bare and seagrass areas did not have statistically different TSMs ($t = 0.75$, $df = 32$, p-value $= 0.46$).

As can be seen in the table above, the samples collected in the vicinity of the working dredges had greater TSM than the other samples (p-value < 0.05). The median and mean values near the dredges were about 20 mg/L higher than other samples.

Ten SPM stations were compared to nearby CBI, TNRCC, and/or WES stations. The TNRCC data were extracted for January through March for 1975 to the beginning of 1999. All the CBI data were used except for the first 50 days of ULM1, ULM2, and ULM3 data, which CBI study personnel indicated may have analytic errors.

Table 24
Comparison of TSM (mg/l) Between Nearby Stations

	Percentile						
Station	25	50	75	Mean	95% CI		n
SPM 5	10.9	20.9	23.7	25.7	11.6	39.7	5
CBI ULM1	13.6	30.3	45.8	37.3	33.2	41.4	413
SPM 6	16.1	17.2	19.0	19.9	11.4	28.4	6
TNRCC 443	18	25	39.5	33.6	22.1	45.1	23

SPM 7 & 8	12.6	13.9	20.3	18.5	12.0	25.0	12
TNRCC 445	10.5	22	37.8	25.5	18.4	32.5	26
SPM 11	29.3	36.0	46.6	41.3	21.4	61.2	6
TNRCC 444	17	28	57.5	37.2	25.0	49.4	23
CBI ULM2	9..9	31.5	65.3	48.2	43.6	52.7	551
SPM ULM3	20.2	20.9	22.3	20.8	18.1	23.5	6
CBI ULM3	6.1	22.3	46.5	30.5	28.0	32.9	594
SPM 17	14.1	21.6	24.7	22.8	9.8	35.8	6
TNRCC 449	21.5	40.5	63.8	57.2	28.6	85.9	14
SPM 20	10.4	13.6	17.3	13.7	7.1	20.3	5
TNRCC 448	19.5	32	53.3	44.0	26.5	61.4	20
SPM 22	20.1	24.0	28.1	24.2	11.2	37.3	4
TNRCC 447	21.5	30.5	42.8	41.6	27.0	56.3	22
SPM LLM1	16.7	20.7	43.1	32.9	-37.9	103.7	3
WES	36	43	110	78.4	48.9	108.1	25
CBI LLM2	65.8	150.5	212.5	161.4	149.6	173.2	388
CBI LLM1-LLM3	76	152	216.3	165.3	158.8	171.8	1328

For comparison to the SPM LLM1 station, CBI data were compiled from (a) CBI LLM2, which was the closest station to the channel, and (b) all data from CBI stations LLM1, LLM2, and LLM3 all within 0.8 km of the channel. The WES data for this location are from 12 different samplings on 6 different days. Samples were collected at multiple depths in some instances. The WES data included samples during normal, as well as extreme wind conditions, when a maximum TSM value of 241 mg/l was measured. The SPM data for this station were apparently collected during favorable weather conditions, were few and variable, and hence have a very wide 95% CI.

Only SPN Station 11 data are close to the corresponding TNRCC data. The TNRCC samples were also collected by boat which also biases the data toward fair weather. The CBI data were collected in more extreme wind and wave conditions. Even so, the corresponding CBI data are similar to those collected at SPM Station 11.

At the same time the SPM sampling occurred, other TSM samples were collected by WES in close proximity of the pipeline dredged-material disposal operation. Samples were taken of the high-concentration underflow formed by the disposal and of the suspension concentration above the underflow. The results of these measurements are reported on the Chapter 5.

Satellite images

Satellite images were acquired near the 1994 to 1995 dredging, disposal, and monitoring period. Relatively cloud-free LANDSAT 5 images were available August, November and December 1994 and May 1995. The high turbidity area described in Chapter 1 showed up clearly in two images. The image for Lower Laguna Madre south of Arroyo Colorado from August 1994, before the September 1994 dredging and three years after the previous dredging in the area, is presented in Figure 34. The corresponding image for November 1994, just after the GIWW was dredged in this area, is presented in Figure 35. These images were used to validate the model suspended-sediment spatial distributions.

Discussion and Conclusions

TSM varied appreciably at locations inside Laguna Madre, especially at the CBI FIX stations. Samples from this area had depth-mean values of 184 and 155 mg/l on November 11, 1997; 43 mg/l on June 18, 1997; 45, 42, and 20 mg/l on December 9, 1996; and 14 mg/l on November 13, 1997. Variability depended on wind conditions and wind-wave resuspension.

At the tidal inlets to the system, time series data indicated that low TSM values occurred during slack tidal conditions. High TSM values occurred at the strengths of flood and ebb tidal phases with no clear indication which tidal phase produced the maximum TSM values or the maximum TSM transport. Tidal transport of TSM at tidal passes can have important implications to the sediment budgets of estuaries, bays, and lagoons. For example, the flood tide between hours 24 and 37 at Brazos Santiago Pass transported approximately 4.1×10^6 kg of suspended sediment (equivalent to about 25,000 yd^3 of channel sediment) into the lagoon according to the data in Figure 24. The ebb tidal phase may remove a similar amount, or somewhat more or less, from the lagoon. At the tidal passes of Lower Laguna Madre, tidal-peak TSM may depend on wind conditions and wind-wave resuspension which occur on both sides of these passes.

Tidal-pass CaCO3 values were higher at Brazos Santiago Pass than at Port Mansfield Pass. The relationships between CaCO3, LOI, and turbidity measurments at Brazos Santiago Pass were similar to those observed in the sediment and floc characterization data taken within Lower Laguna Madre: high CaCO3 content associated with low TSM or turbidity and low LOI associated with low CaCO3. However, at Port Mansfield Pass, CaCO3 and LOI content were inversely correlated and their relationship to turbidity was less clear.

The WES PAR measurements were consistent with the functional relationship between K_d and TSM previously developed by Burd and Dunton (2000). They used a polynomial fit to their data and found

$$TSM = 0.15937\,K_d^2 + 13.9\,K_d - 4.569 \qquad (33)$$

Figure 34. LANDSAT 5, band 3 image from Port Isabel to Arroyo Colorado taken 20 August 1994 with 0.7- and 1.4-m depth contours and station locations superimposed (coordinates are UTM zone 14, NAD83, in meters)

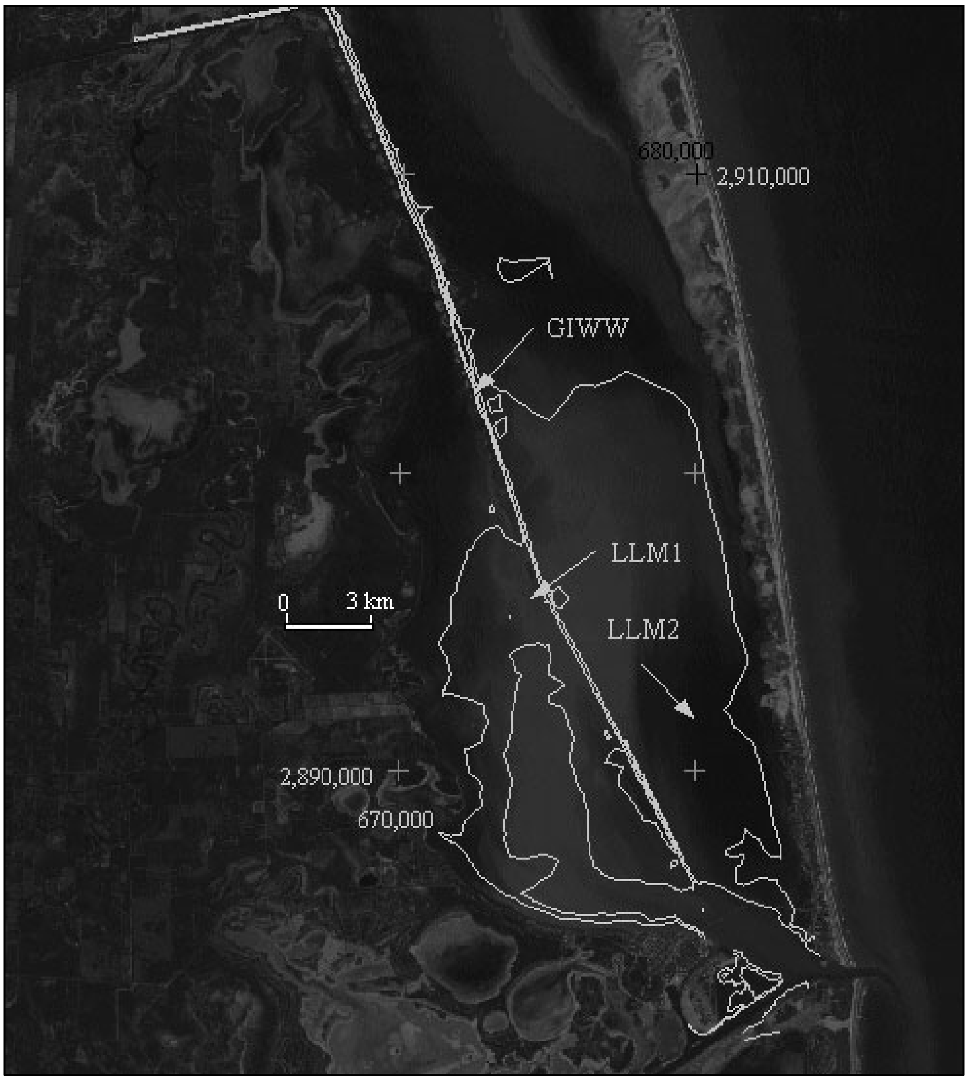

Figure 35. LANDSAT 5, band 3 image from Port Isabel to Arroyo Colorado taken 24 November 1994 with 0.7- and 1.4-m depth contours and station locations superimposed (coordinates are UTM zone 14, NAD83, in meters)

Plots of mean diffuse attenuation K_{dm} and $K_d(z)$ versus TSM concentration are shown in Figures 36 and 37 . The function of Burd and Dunton (2000) is also shown in these plots. The agreement between the WES measurements and the function can be seen to be reasonably good, within the scatter of these data. The mean K_{dm} values reported here are probably more reliable than point values.

The sediment and floc characterizations indicated that fine flocs occur at lower TSM concentrations, and that these fine flocs have high levels of CaCO3 and LOI. As more bed sediment is resuspended, flocs become larger and have lower levels of CaCO3 and LOI.

The quantity of water-column TSM is the dominant factor controlling light conditions. Dissolved organic matter was found to be low in Lower Laguna Madre during November 1997. Aggregation of eroded sediments is rapid and most material redeposits within about 36 hours of the cessation of high-wind events. The finest suspended sediment particles are carbonate. Aggregation depends to some extent on turbulent mixing, which may indicate that dredging during time periods that included high-energy events would hasten the aggregation and deposition process for suspended material. Conversely, if dredging and disposal were conducted during extended quiescent periods, dispersed sediment may remain in the water column for an extended period of time (Knowles 1998).

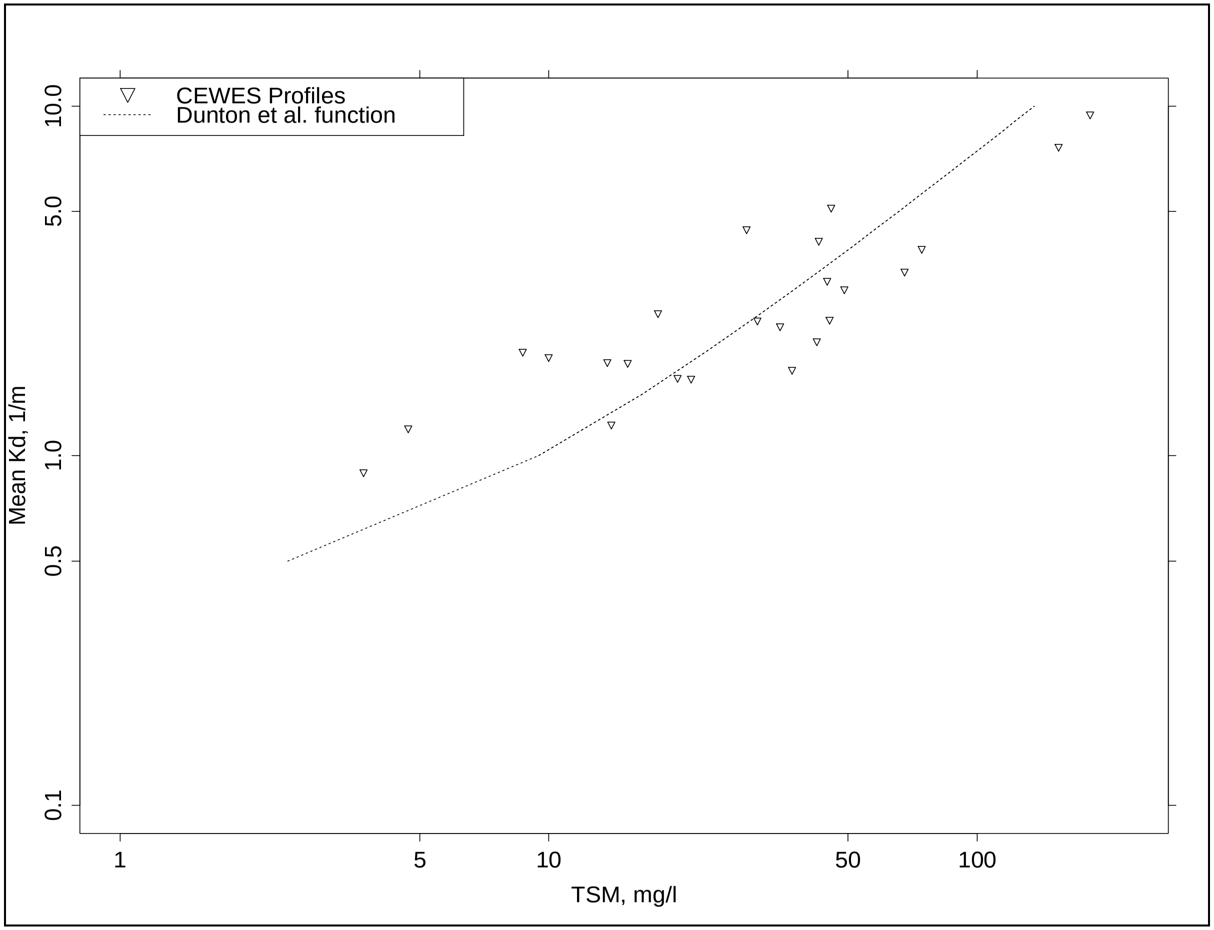

Figure 36. Depth-mean K_{dm} versus TSM for the three WES surveys

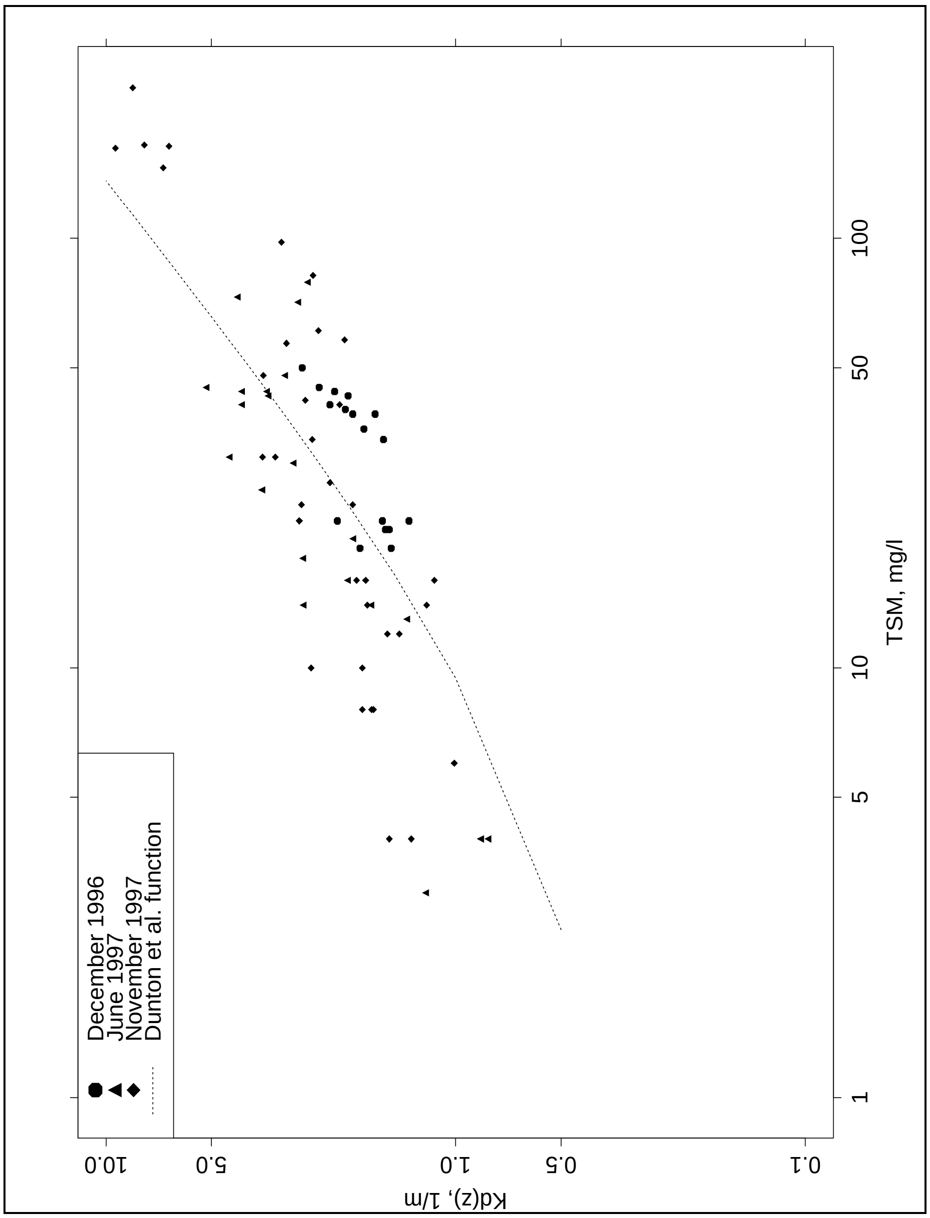

Figure 37. Point K versus TSM_m for the three WES surveys